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Space Administration

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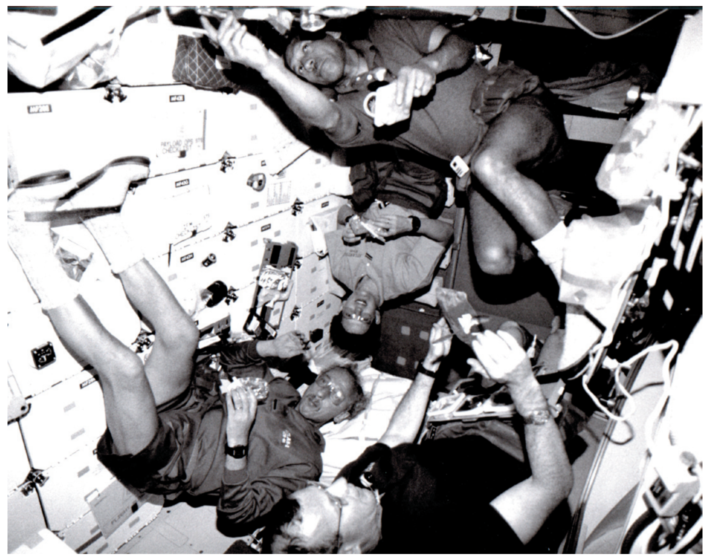
Educational Brief

The Effects of Space Flight on the Human Vestibular System

How does the human body maintain a sense of body position and balance on Earth, while flying in an airplane, or traveling through space?



Mealtime for the STS-45 crew. Up and down is a matter of personal perspective.

Introduction

The presence of sensory and response systems is a universal attribute of life as we know it. All living organisms on Earth have the ability to sense and respond appropriately to changes in their internal and external environment. Organisms, including humans, must sense accurately before they can respond appropriately, thus ensuring survival. If our senses are not providing us with reliable information, we may take an action which is inappropriate for the circumstances and this could lead to injury or death.

How Many Senses?

We are all familiar with the question, "How many senses do humans have?" The answer we hear most often is five: sight, taste, smell, hearing, and touch. (Touch itself includes heat, cold, pressure, and pain.) Actually, there are many other senses - hunger, thirst, kinestethic, etc. One of the most powerful of the other senses is the vestibular sense provided by the vestibular system. It is our ability to sense body movement combined with our ability to maintain balance (equilibrium). The human body has a remarkable ability to sense and determine the direction and speed in which it is moving (linear and angular acceleration), and maintain balance (postural equilibrium).

Human beings have the ability to walk a tight rope, do repeated pirouettes in a ballet performance, combine twists and turns when diving, or perform triple toe loops while ice skating…and all (usually) without losing balance and while keeping track of the relative position of arms and legs with respect to the rest of the body. Incredible!

How does the human body sense and control the movement so precisely? How do we maintain our balance while putting ourselves through a wide variety of spinning and tumbling activities which are inherently "unbalancing?" When we are in motion, how do we know what direction and at what speed we are moving? How do these important body senses change (adapt) when we fly in an aircraft or enter the microgravity environment of low-earth orbit? Can these sensory and response systems, which serve us so well here on Earth, provide us with inaccurate and potentially harmful information when we fly as pilots or astronauts? Let's find out!

Maintaining equilibrium, sensing movement, and maintaining an awareness of the relative location of our body parts requires the precise integration of several of the body's sensory and response systems including visual, vestibular, somatosensory (touch, pressure and stretch receptors in our skin, muscles, and joints), and auditory. Acting together, these body systems constantly gather and interpret sensory (input) information from all over the body and usually allow us to act on that information in an appropriate and helpful way.

Body movements undertaken in the every day (Earth normal) environment usually do not upset our sense of balance or body orientation. However, we have all experienced dizziness and difficulty walking after spinning around in a circle. Astronauts experience similar sensations of dizziness and disorientation during their first few days in the microgravity environment of space. Microgravity is an environment created by freefall in which gravity's effects are greatly reduced. (For more information about the topic of microgravity, refer to NASA's Microgravity Teacher's Guide. [EG-1997-08-110-HQ] See the reference section for information on how to obtain this product.)

Upon arriving back on Earth (after prolonged exposure to microgravity), astronauts frequently have difficulty standing and walking upright, stabilizing their gaze, and walking or turning corners in a coordinated manner. An astronaut's sense of balance and body orientation takes time to re-adapt to "Earth-normal" conditions. How does the unique gravitational condition encountered in space flight affect an astronaut's sense of body orientation, movement, and balance?

Might a better understanding of this microgravity-induced vestibular function help people back on Earth prevent the dizziness, disorientation and susceptibility to falling that some older members of our population experience? Answers to these important and interesting questions require us to know more about the anatomy (structure) and physiology (function) of the human vestibular system on Earth as well as in space.

NASA has been investigating the human vestibular system's adaptation to the space environment for many years. Important experiments were performed on STS-40 (Spacelab-1), STS-58 (Spacelab-2), and the Neurolab (STS-90) missions. Building on what we have learned from previous flight and ground-based experiments, the STS-107 mission includes additional post-flight experiments to help us better understand the physiology of our vestibular system.

Things to Know: Vocabulary Building

(Please refer to Figure 1 as we learn some important and interesting facts and terms about the ear and vestibular anatomy and physiology.)

The ear is composed of structures organized within into three distinct anatomical regions; an outer ear which extends from outside the body through the ear canal to the tympanic membrane (ear drum), a middle ear composed of an air filled cavity containing three tiny bones called ossicles which transmit and amplify sound between the ear drum and the cochlea (where the sense of hearing is located), and the inner ear, composed of the cochlea and the vestibular system (see below).

The vestibular system (Figure 2), which is key to our senses of balance, motion and body position, is comprised of three semicircular canals connected to two membranous sacs called the

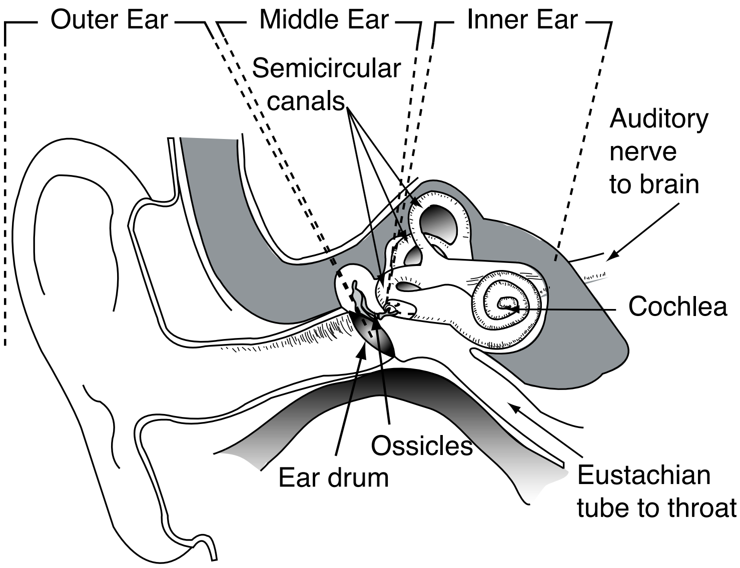


Figure 1: The Outer, Middle, and Inner Ear

saccule and *utricle*. The saccule and utricle are often referred to as the *otolith* organs. You will soon see why.

The semicircular canals are oriented along three planes of movement, with each plane at right angles to the other two. Pilots and astronauts call these three planes of rotation *pitch* (up and down; nod your head "yes"), *roll* (tumbling left or right; move your head from your left to your right shoulder or vice versa) and *yaw,* (lateral movement left and right; shake your head "no"). The semicircular canals allow us to sense the direction and speed of angular acceleration. The otolith organs allow us to sense the direction and speed of linear acceleration and the position (tilt) of the head.

What's the difference between angular and linear acceleration? Lots! Linear acceleration is a change in velocity (speed increasing or decreasing over time) without a change of direction (straight line). Angular acceleration is a change in both velocity and direction at the same time. For example, imagine you are in a stopped car. The driver of the car steps on the accelerator and you accelerate straight ahead. The driver steps on the brake pedal and you decelerate to a stop. Then the driver puts the car in reverse and you accelerate straight backwards and the driver slams on the brakes once again. You have just experienced linear acceleration and deceleration (forward and backward). Your movement was along a straight line and your otolith organs helped you sense these linear accelerations and decelerations.

Now, imagine yourself on a roller coaster. You start out accelerating straight ahead, just like in the car. Then, suddenly, the track dips almost straight down and you "pitch" forward. Then the nose of your car (and you) come almost straight up. You have just experienced downward and upward pitch. Now the roller coaster, while staying perfectly flat on the track, takes a severe left turn followed by a right turn. You have just "yawed" to the left and right. Now comes the really fun part. Your roller coaster and the track it is on does a complete 360-degree roll, first to the left and then to the right. Makes you dizzy just thinking about it, right? Your semicircular canals helped you sense these angular accelerations. You have now experienced the three planes of angular acceleration; pitch, yaw, and roll. An aircraft, a spaceship or any vehicle operating in three-dimensional space can accelerate in these three planes of rotation (often along more than one plane at the same time).

The vestibular system also helps you maintain a fixed gaze on a stationary or moving external object while you are undergoing complex head and body movements. Look at the clock on the wall. Now move your head sideways or up and

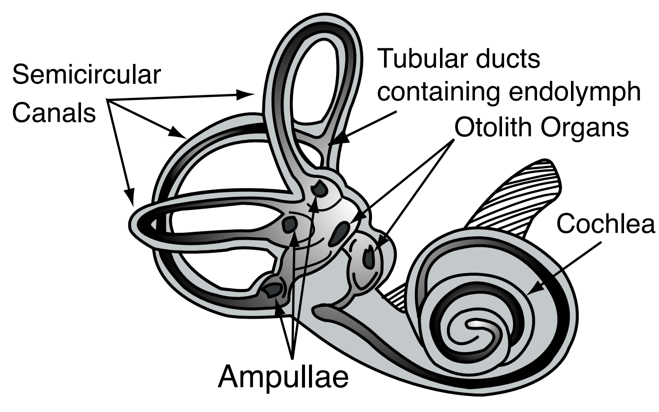


Figure 2: The Vestibular System - semicircular canals and otolith organs

down or even in a circle. Your eyes stay fixed on the clock. With slow movement, the eyes are kept stationary by visual mechanisms only. As the speed of movement increases, the vestibular system takes over the image stabilization process. We'll have fun with this later when we use a teaching tool called the *Barany Chair.*

Although they are both located within the vestibular apparatus of your inner ear, are interconnected, and operate using similar physical principles, the sensory mechanisms which allow you to detect linear acceleration (otolith organs) are structurally and functionally different than those which allow you to detect angular acceleration (semicircular canals).

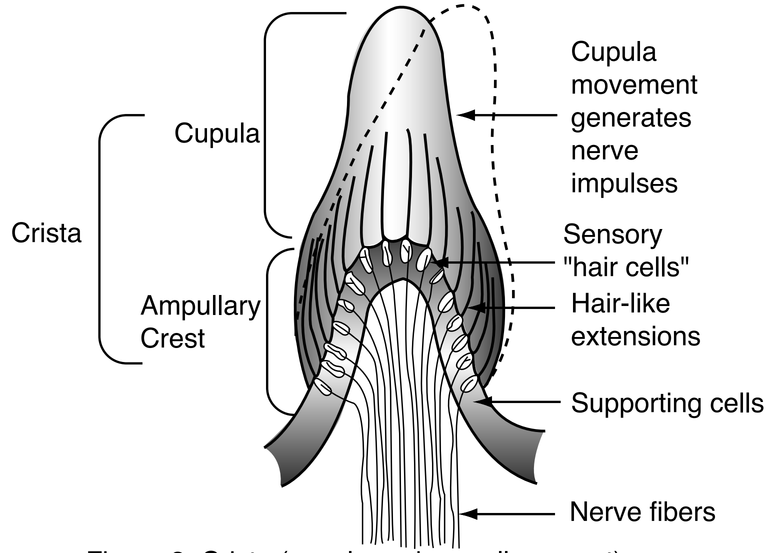


Figure 3: Crista (cupula and ampullary crest)
When movement of endolymph causes cupula to bend, sensory hair cells generate nerve impulses which the brain perceives as angular acceleration.

Vestibular Physiology: How Structure Supports Function

Now that you understand the location and overall shape of the components of your vestibular system and their respective roles in providing you reliable sensory input, let's investigate the structure and functions of these important components of your sixth sense.

First, look at Figures 3 and 5 for a more detailed view of the structures within the vestibular system. You will notice that all vestibular organs (semicircular canals, saccule, and utricle) functionally rely on a common type of receptor cell, called a *hair cell.*

The Semicircular Canals (Figure 2)

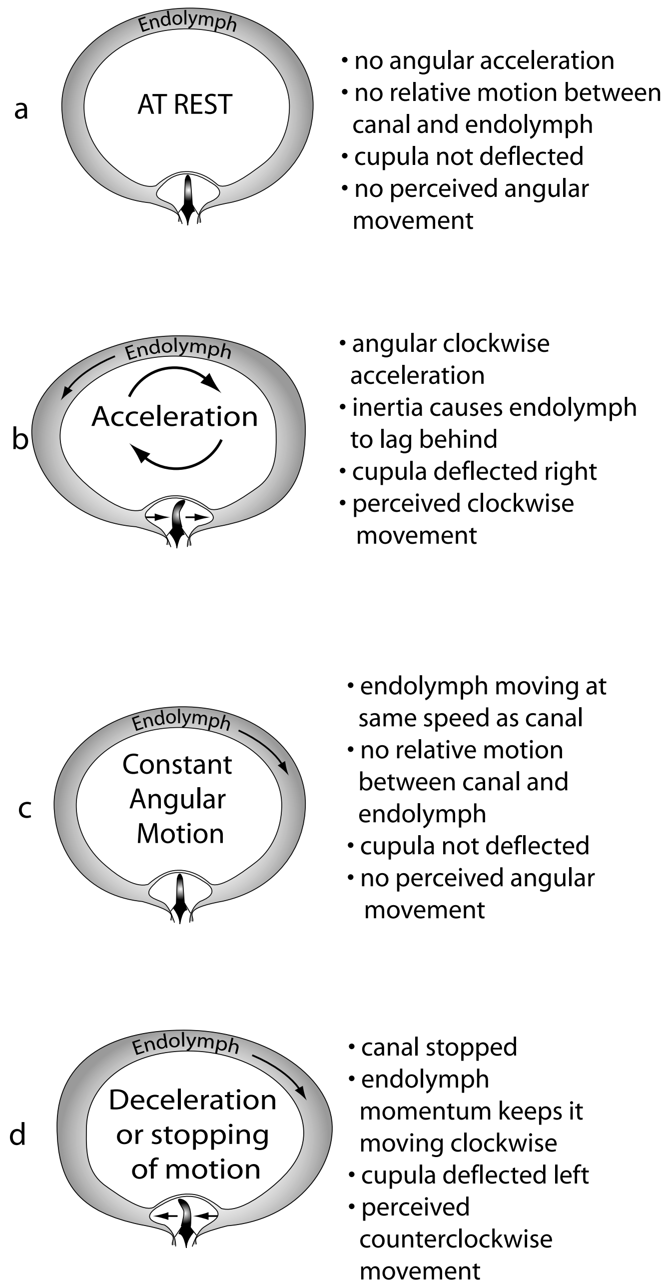
The semicircular canals are tubular membranous structures imbedded within a bony structure of the same shape. The central cavity of each of the three tubular structures (canals) is filled with a fluid called *endolymph.* Each endolymph-filled canal has an enlarged area near its base called an *ampulla.*

Parts of the vestibular nerve penetrate the base of each ampulla and terminate in a tuft of specialized sensory cells (hair cells). The hair cells are arranged in a mound-like structure, the ampullary crest. Rising above the *ampullary crest* is the *cupula,* consisting of the hair-like extensions of the hair cells surrounded by a gelatinous material arranged into a wedge-shaped structure, the cupula. When the endolymph moves (or the cupula moves and the fluid remains stationary), the gelatinous tip of the cupula and the hair cell extensions embedded within it are displaced to one side or the other.

When the embedded hair cells bend, they send a signal via the vestibular nerve to the brain where the information is evaluated and appropriate action is initiated. The entire structure consisting of the ampullary crest and the cupula is called a *crista* (pl = cristae; pronounced KRIS-tee).

Now, as we ready ourselves to discuss how the semicircular canals actually function to "sense" angular acceleration, we need to review some physics; specifically, the Law of Inertia, "A body at rest remains at rest unless acted upon by an unbalanced force."

Figure 4: The effects of angular acceleration on the semicircular canals



This means that, if you were to begin accelerating along one of the three planes of rotation (pitch, roll, or yaw), structural components of the corresponding semicircular canal would begin moving immediately (since they are attached to the rest of your head). However, (this is important) the endolymph (fluid) within that particular semicircular canal would tend to "remain at rest" due to inertia. It would lag behind the structural components, deflecting the cupula and generating a nerve impulse to the brain.

Initially, the membranous tubular and cellular structures move but the fluid does not. Thus, there is relative movement between the fluid and the rest of the semicircular canal. (see Figure 4b) Eventually, due to friction and the drag it induces, the fluid begins to move at the same speed as the components within which it is contained. When this occurs, the cuplula is not deflected and, even though your body is continuing to angularly accelerate, the acceleration is not "sensed." You incorrectly perceive that you are stationary. (see Figure 4c)

Now, let's stop your angular acceleration suddenly. What happens? The moving fluid now has momentum and so it continues to move until drag brings it to a stop. In other words, fixed structures of your semicircular canal stop immediately (since they are still attached to your head which is still attached to your body) but the endolymph fluid continues to move in the direction of (previous) movement. The Law of Inertia also states that a "body in motion will continue in motion in a straight line unless acted upon by an unbalanced force." Now, the cupula and the embedded hair cells are bent in the opposite direction and you incorrectly sense that you are accelerating in the direction opposite to your previous acceleration even though you are completely stopped! (see Figure 4d)

Don't believe it? Later, we'll do an experiment using the Barany Chair that will demonstrate this phenomenon to you. Be prepared.

Saccule and Utricle (Figure 5)

As previously noted, the saccule and utricle are referred to collectively as "the otolith organs." Angular acceleration and deceleration primarily affect the semicircular canals and entirely depend on the relative movement of endolymph with respect to the cupula. The saccule and utricle sense linear acceleration and are affected by gravity. They also provide you with information concerning changes in head position (tilt).

Both the saccule and the utricle contain a thickened patch of specialized cells called a macula that consists of sensory hair cells interspersed with “supporting” cells. (see Figure 5) The free hair-like tufts extending from the hair cells are embedded in a gelatinous *otolithic membrane* which supports small piles of calcium carbonate crystals on its surface. Collectively, these calcium carbonate crystals are called *otoliths* (F *otolithe*, fr. oto = ear; lithos = stones).

The otoliths increase the mass of the otolithic membrane which gives it more inertia (tendency to remain at rest). On Earth, when the head is tilted to the left or right, forward or back, the otoliths tend to move along the gravity gradient (downwards). Even a slight movement of the otolith membrane is enough to bend hair cells and send sensory information to the brain. A similar inertia and gravity-dependent process occurs when you accelerate linearly…up or down, forward or backward.

Because of the way they are situated within the vestibular apparatus, the saccule is more sensitive to vertical acceleration (e.g., riding in an elevator) and the utricle is more sensitive to horizontal acceleration (e.g., riding in a car).

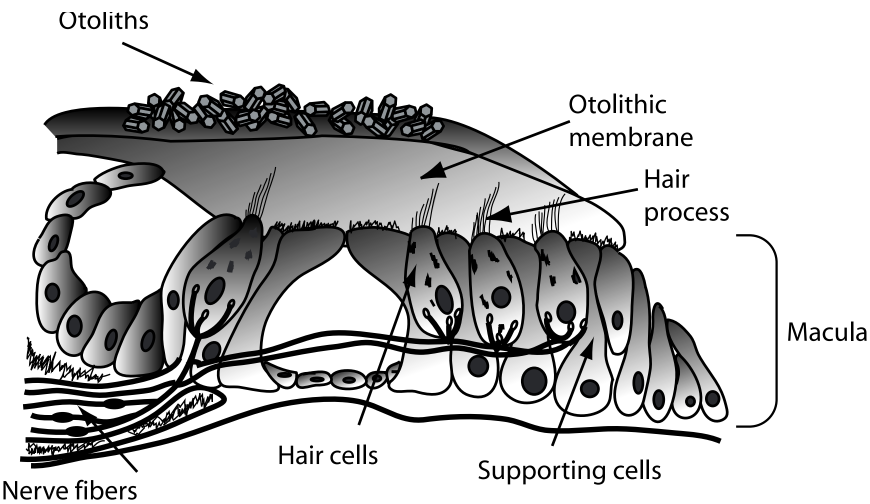


Figure 5: Otolith Organ (saccule or utricle). Senses linear acceleration.

The actual physiology (functioning) of the otolith organs is remarkably similar to the physiology of the semicircular canals. Both depend upon inertia and the mechanical deflection of hair cells to initiate nerve impulses that are sent to the brain and interpreted as body movement. The brain then reflexively initiates appropriate “corrective” actions within the nervous, visual, and muscular systems to ensure that situational awareness and balance are maintained.

Let’s reexamine our previous example of rapidly accelerating straight ahead in a car. During forward acceleration, due to inertia, the utricle’s otolith membrane and its associated otoconia tend to lag behind the portion of the utricle that is firmly attached to the head. This causes the hair cells whose hair-like extensions are embedded within the otolith membrane to be deflected backwards. This backward deflection causes sensory nerves to fire and this provides the brain with information on the direction and speed of acceleration. You can imagine a similar process occurring within the saccule when you are in an elevator and it either begins to rise or descend rapidly.

Vestibular Sense

Our vestibular system enables us to determine body orientation, the direction and speed at which we are moving, and maintain balance.

When vision is removed (as is common in many flight situations) we rely more heavily on our vestibular sense for this information. However, in flight and in space, our vestibular system (designed to work on the ground in a 1-G environment) often provides us with erroneous or disorienting information. The results can be tragic.

Understanding how the various organs that comprise this system work will lead to improved adaptation strategies for astronauts entering a microgravity environment and returning to an Earth normal environment. It will also help military and civilian pilots and people on Earth who are prone to dizziness and disorientation. We could all benefit from NASA's scientific research on the vestibular system.

For The Classroom

Following the glossary section of this publication are instructions for constructing a special rotating seat called the Barany Chair. It is a chair with a bearing supporting the axle that permits a person sitting in the chair to spin many times with a single push. The vestibular illusions that will be described work best with a Barany Chair. However, some good results can be obtained through the use of a swivel office chair. The bearings on office chairs do not permit continuous rotation. Additional pushing is needed and it is essential that the pushes be uniform for the illusions to be felt. Also, office chairs are lower to the floor and a student's feet may bump or drag, ruining the illusions.

Glossary

Ampulla - (pl = ampullae) expanded area within each semicircular canal which contains a crista; used to detect angular acceleration.

Crista - (pl = cristae) within ampullary region of semicircular canal; name given to structure composed of ampullary crest (hair cells) combined with the cupula.

Cupula - One component of a crista; sits atop ampullary crest and is composed of hair-like extensions of sensory hair cells embedded within a gelatinous mass.

Endolymph - fluid within semicircular canals which, when it moves, deflects the cupula and initiates the sensation of angular acceleration.

Inertia - the fundamental property of inert material tending to resist changes in its state of motion.

Macula – (pl = maculae) thickened area within saccule and utricle consisting of hair cells and supporting cells. In both the saccule and utricle, the macula is covered by the gelatinous otolithic membrane containing otoliths.

Momentum - tendency of a body in motion to resist a change in that motion.

Nystagmus - repeated rapid eye movements.

Otolith - calcium carbonate crystals adhering to and embedded within otolithic membrane of saccule and utricle (otolith organs).

Otolith organs -saccule and utricle, primarily responsible for sensing linear acceleration as well as head position (tilt).

Pitch - rotational motion carried out along a front to back vertical plane.

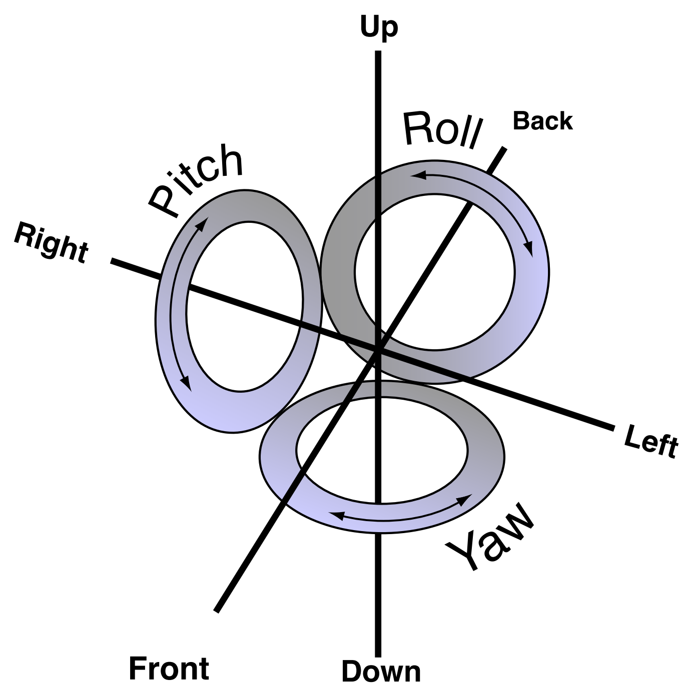


Figure 6: Roll, Pitch, and Yaw planes of motion

Roll - rotational motion carried out along a lateral vertical plane.

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Saccule - one of the two types of otolith organs of the vestibular system; used to sense linear acceleration and the position (tilt) of the head.

Semicircular canals - three fluid-filled circular tubular structures within each inner ear which are arranged at right angles to each other and are responsible for sensing angular acceleration.

Sensory hair cells - common name given to sensory cells located within semicircular canals and otolith organs.

Somatosensory - integrated sensory system- which combines individual inputs from skin, muscles, tendons and stretch receptors throughout the body.

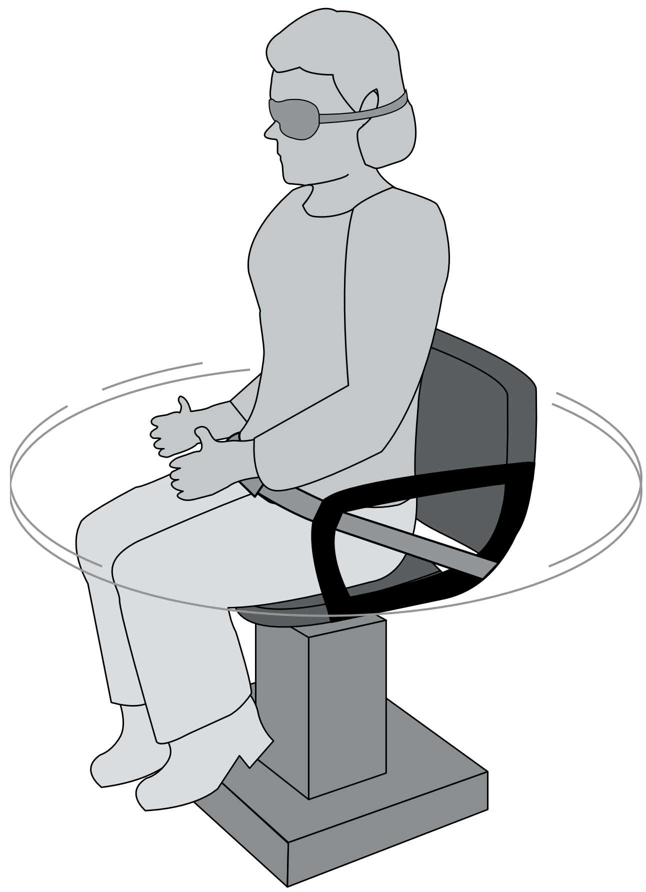
Vestibular system- the semicircular canals and the otolith organs (Responsible for sensing angular and linear acceleration, respectively.)

Sensory hair cells - common name given to sensory cells located within the ampullary crest of semicircular canals and the macular region of saccule and utricle (otolith organs)

Yaw - rotational motion carried out along a horizontal plane.

Constructing the Classroom Barany Chair

The classroom Barany chair consists of a pedestal base, bearing mechanism, and a chair with a seat belt. The Barany chair pictured here uses an executive style office chair seat. Any kind of desk chair can be used but an armchair is recommended.



The following plans will enable you to construct a classroom Barany Chair using basic powered and un-powered hand tools. Most materials for the chair are available from a hardware/lumber store. The chair bearing, obtainable from an auto parts store or automobile salvage yard, is a rear axle bearing from a front wheel drive vehicle either from an auto parts store or an automobile salvage yard. Complete material lists are included in the assembly diagrams. The total cost for the chair, assuming all parts are purchased, will be approximately one hundred and fifty dollars.

Constructing the Base

The base for the classroom Barany chair consists of a square frame constructed from two by four lumber and a thick plywood platform made from two 24-inch square pieces of 3/4-inch plywood glued together. An alternate base can be constructed from an unfinished round wooden tabletop available from lumberyards. The top is approximately 30 inches in diameter and 1 1/2 inches thick. Attach an X of wood strips beneath the platform with screws and glue. Drill holes and insert tee-nuts into the ends of the X so that adjustable leveling glides can be screwed into the nuts. The glides, available from hardware stores, will enable easy leveling of the Barany Chair.

Constructing the Pedestal

The bearing and the chair seat will be attached to a pedestal mounted on top of the base. The pedestal consists of a square set internal frame made from 2”X2” or 2”X4” lumber. The frame is held together with screws and glue. Plywood or 3/4 inch clear pine boards are used to cover the outside of the frame. The facing provides additional strength as well as improve the appearance of the pedestal. Glue and screw three of the facing sides but use screws only for the fourth side. This provides an access door to tighten bolts and nuts when necessary.

The top of the pedestal is covered with two layers of 3/4” plywood that are glued together. Before gluing, the main hole for the bearing mechanism must be drilled. If you use the bearing called for in the materials list, two holes of different sizes must be drilled. The lower plywood sheet must have a 2 1/2” hole and the upper sheet must have a 3” hole. The holes are cut with hole saws (available from hardware stores). The two holes must be concentric to fit the bearing. If a different

A Note About Measurement Units
British Units of measurement are used here because Metric-sized lumber and hardware are not generally available in the United States.

bearing is used, cut the mounting holes to fit its shape. Drill the bolt mounting holes for the bearing. Insert the bearing and bolts and tighten the nuts to hold it firmly.

The pedestal can be mounted permanently to the base with screws and glue. If desired, the pedestal can be removable by attaching it to the base with nuts and bolts. Tee-nuts can be inserted into drilled holes from the bottom of the platform. These remain in place even when the chair is disassembled.

Attaching the Chair to the Pedestal

Assemble the parts for the bearing mechanism. The 3/4-inch pipe nipple has to be specially made to fit the chair and the bearing. The nipple can be cut and threaded for a modest charge at a hardware store. The exact length of the nipple will depend upon the design of the seat bracket of the office chair you use. If you purchase a new chair, do not attach the pneumatic tube to the bracket. The pipe nipple will be used instead. If using an existing chair, the tube has to be removed. Remove the chair seat and tap the bracket until the tube slips out of the bracket. Thread two 3/4 inch galvanized lock nuts on to the long threaded end of the nipple (see diagram). Insert the nipple into the hole for the pneumatic tube and a third lock nut is threaded on to the nipple to tighten the nipple in place. The bracket is now attached to the seat bottom.

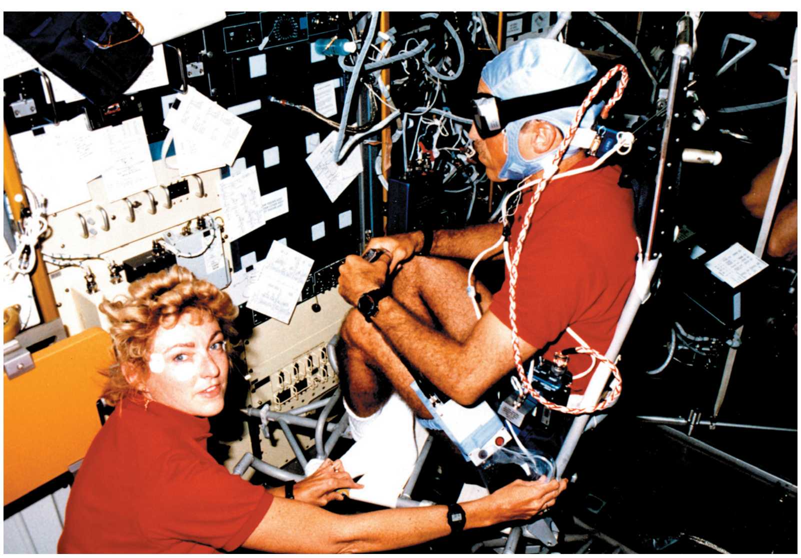
Set the rigid connector, shown in the mechanism diagram, over the bearing. Lower the chair over the pedestal until the pipe nipple slides through the connector and into the hole of the bearing. Hold the nipple in place with another lock nut underneath the bearing. (This is where an access panel comes in handy.) When tightened properly, the chair should have no wobble and be able to spin freely.

Attaching the Safety Belt

A lap belt can be made from wide hook and loop tape or from webbing and buckles available from an outdoors store that features climbing equipment. Attach the rear ends of the belt to the chair uprights. Cut the strap length to fit your students.

Safety Precautions

Be sure to follow the instructions for use of the Classroom Barany Chair. Do not let students treat the chair as an amusement ride. **Use the safety lap belt at all times.** Assist students getting into and out of the chair. A small stepstool can be useful for this. Provide a chair for the volunteer to sit on for a few minutes following the demonstration until any dizzy effects wear off. Perform only one illusion at a time. If a student wants to try other illusions, wait for a few minutes to allow the effects of the first illusion to dissipate. It is recommended that you interview student volunteers before they ride the Barany Chair to find out if they are susceptible to motion sickness. Have a container or plastic bag ready just in case.



Astronaut James P. Bagian, mission specialist, sits in a Barany Chair while wearing an accelerometer and electrodes to record head motion and eye movements during rotation. Payload specialist Millie Hughes-Fulford assists with the test during the STS-40 mission.

Barany Chair Base Construction

Construction Notes:

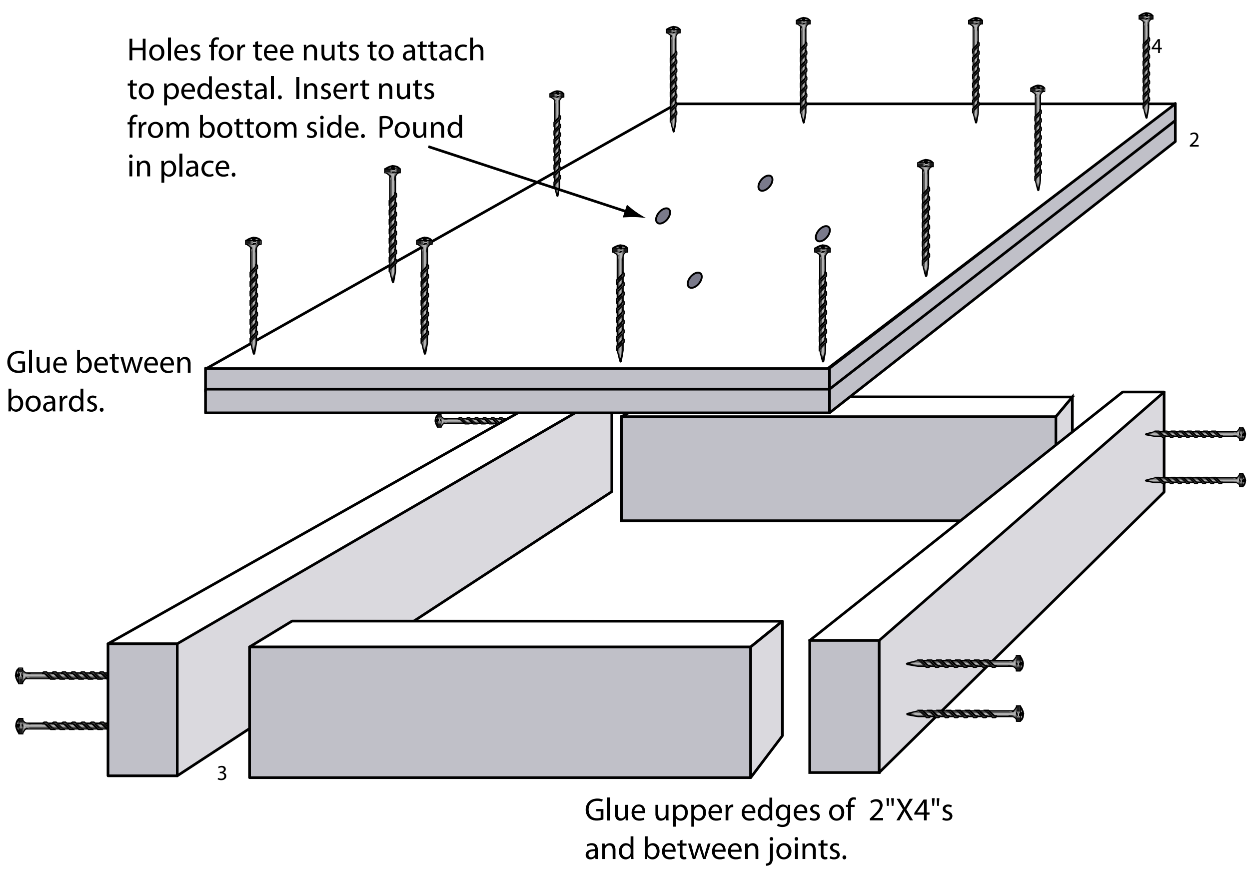
- Be sure to follow all manufacturer instructions for safe operation of tools and use of materials employed in the construction of the Classroom Barany Chair.
- Two by four lumber is cut slightly smaller than 2"X4". Choose a straight piece and saw into four pieces to make a 24"X24" base.
- Precut 24"X24" plywood is available at many hardware stores.
- Assemble the 2"X4" frame with screws and glue. Be sure to pre-drill pilot holes for screws.
- Drill pilot holes through plywood boards into the lower frame. Glue the boards and screw them into the frame. Countersink the screw so that they lie beneath the wood surface.
- Drill holes in the base for the tee-nuts. Match the positions of the holes to the mounting holes in the bottom of the pedestal. Be sure to insert the tee-nuts into the base from the underside of the plywood.

Materials List

Number	#pcs	item	specifications
1.	1	wood glue	carpenter grade
2.	2	plywood	24"X24"X3/4"
3.	1	two by four	8'X2"X4"
4.	28	wood screws	#10, 3" Phillips
5.	5	tee nuts	3/16"

Tools

- Electric hand drill - 3/8" or 1/2"
- Drill bit for pilot holes and for tee nut holes
- Countersink bit
- Phillips head screw driver or Phillips head bit for drill
- Hand saw - crosscut
- Ruler
- Square
- Hammer



Barany Chair - Pedestal Construction

Construction Notes:

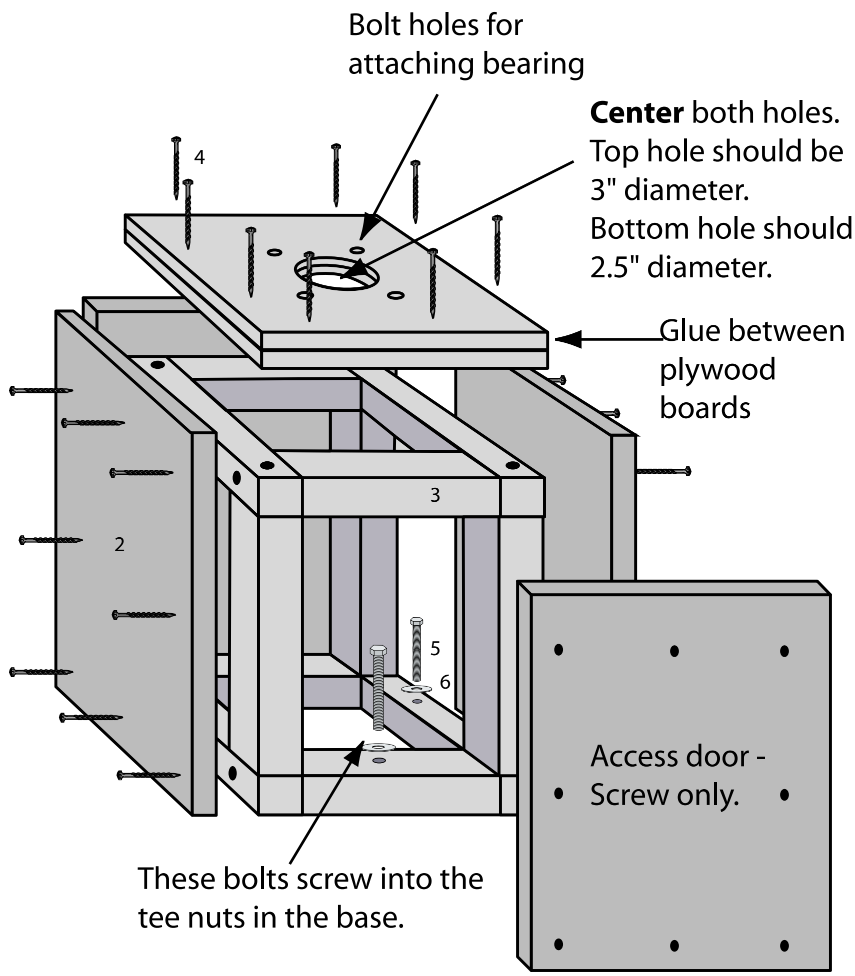
- Be sure to follow all manufacturer instructions for safe operation of tools and use of materials employed in the construction of the Classroom Barany Chair.
- The interior square set frame should be constructed from 2”X2” or 2”X4” lumber. The finished size of the pedestal should be 12” wide, 12” deep, and 12” to15” high depending upon the size of your students. The lengths of the frame pieces you cut will depend upon the size of the wood you use.
- Screw and glue the square set frame together. Be sure to countersink the holes so that the screw heads are flush with the wood. Offset the pilot holes of intersecting screws so that they do not hit each other.
- Face the frame with 3/4” clear pine or plywood. Screw and glue three of the sides but attach the forth side with screws only. This becomes an access panel for tightening bolts.
- The top platform is made from two 3/4 inch plywood pieces glued together. Before gluing, determine the center of each board. Drill a 2.5” hole with a hole saw (hole saws are available from hardware stores) through the center of the lower board. Drill a 3” hole through the center of the top board. Align them carefully before gluing.
- This design shows 3/16” by 3 1/2” hex bolts used for attaching pedestal to the base. The bolts screw into tee-nuts coming upward from the bottom of the base. This permits easy removal the pedestal from the base. If preferred, the pedestal can be permanently fixed to base with glue and screws.

Materials List

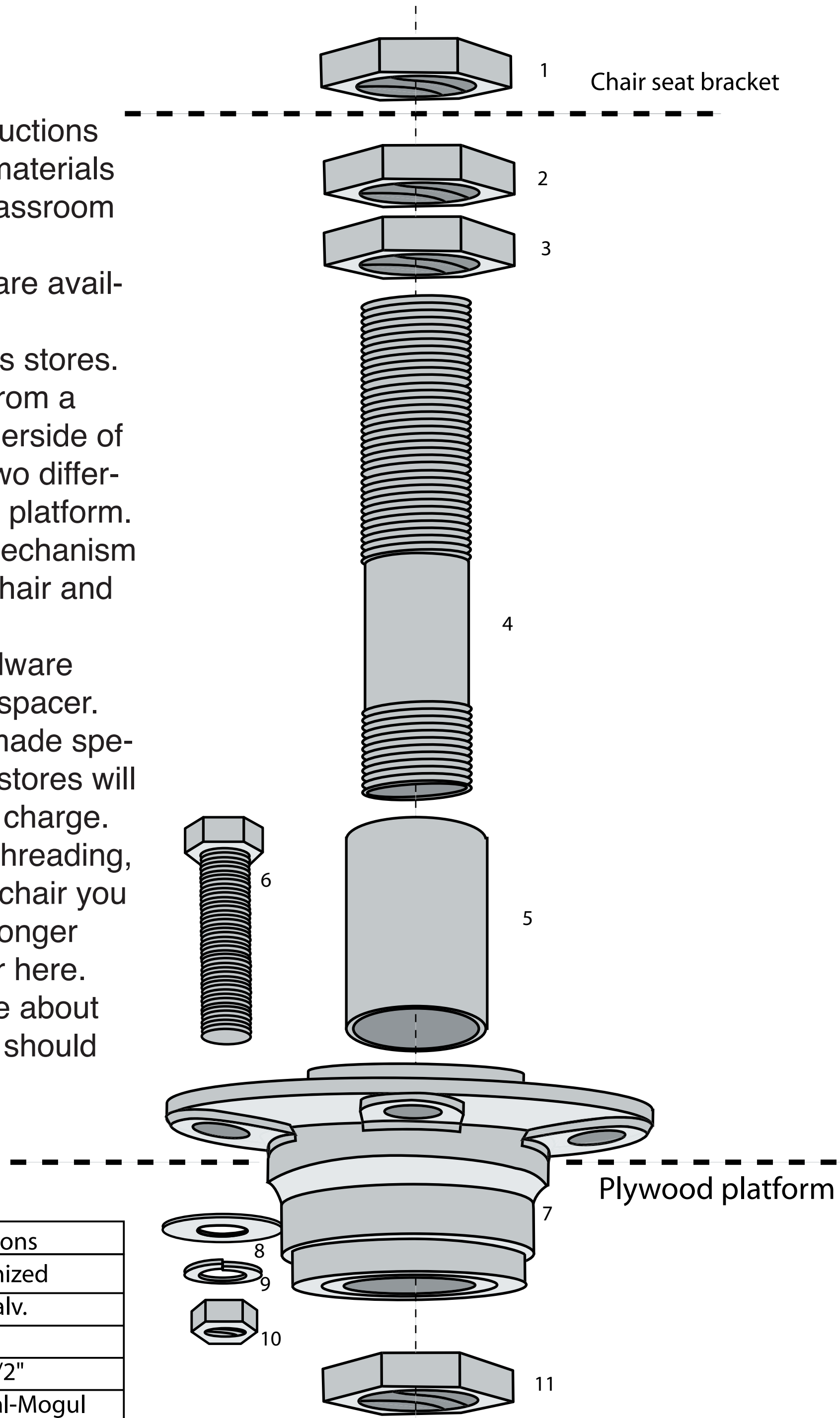
Number	#pcs	item	specifications
1.	1	wood glue	carpenter grade
2.	2	plywood	48" X 48" X 3/4"
3.	4	two by four	8' X 2" X 4"
4.	56	wood screws	#10, 3" Phillips
5.	4	hex bolts	3/16" X 3 1/2"
6.	4	cut washers	3/16"

Tools

- Electric hand drill - 3/8" or 1/2"
- Hole saws - 3" and 2 1/2" with drill attachment
- Drill bit for pilot holes
- Countersink bit
- Phillips head screw driver or Phillips head bit for drill
- Hand saw - crosscut
- Ruler
- Square



Barany Chair - Bearing Mechanism

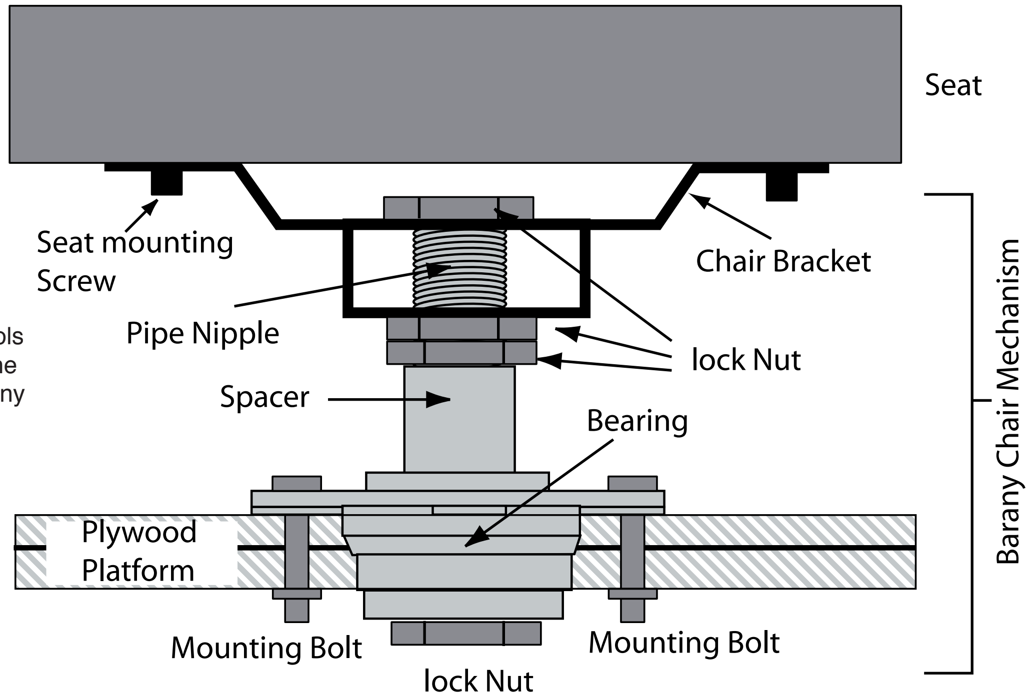


Construction Notes:

- Be sure to follow all manufacturer instructions for safe operation of tools and use of materials employed in the construction of the Classroom Barany Chair.
- Except for the bearing, all metal parts are available from hardware stores.
- The bearing is available from auto parts stores. It is a free-spinning rear axle bearing from a front wheel drive automobile. The underside of the bearing is tapered, necessitating two different sized holes in the plywood bearing platform.
- The dashed lines indicate where the mechanism is attached to the seat bracket of the chair and to the plywood platform.
- The ridged connector comes from hardware electrical departments. It serves as a spacer.
- The galvanized pipe nipple has to be made specially for the Barany Chair. Hardware stores will cut and thread pipe for you for a small charge. Before specifying the final length and threading, examine the seat bracket of the office chair you are using. You may require a slightly longer or slightly shorter nipple than called for here. The upper end of the nipple will require about 4 inches of thread while the lower end should require only about 1 inch.

Parts List

Number	#pcs	item	specifications
1-3.	3	lock nut	3/4", galvanized
4.	1	pipe nipple*	6" X 3/4" galv.
5.	1	rigid connector	1"
6.	1	hex bolt	5/16" X 2 1/2"
7.	1	rear axle hub bearing	BCA Federal-Mogul Bearings, #522025
8.	1	cut washer	5/16"
9.	4	lock washer	5/16"
10.	4	hex nut	5/16"
11.	1	lock nut	3/4", galvanized



Be sure to follow all manufacturer instructions for safe operation of tools and use of materials employed in the construction of the Classroom Barany Chair.

Attaching the Office Chair Seat

Office chair seat brackets usually consist of a metal plate with a hole for inserting the tubular pedestal extending upward from the legs and castors. The tubular pedestal, legs, and castors are not needed for the Barany Chair. Instead, the custom-made galvanized pipe nipple substitutes for the tubular pedestal. Assemble the chair by first removing the seat bracket from the bottom of the seat. Twist two lock nuts on to the long threaded end of the pipe nipple. Keep them loose and below the point where the bracket will rest. Insert the nipple into the seat bracket hole and twist another lock nut on the upper end of the nipple. Tighten the first and the second lock nut to the bottom of the bracket. The two lock nuts working together will resist later loosening. Reattach the seat bracket to the seat. Slide the other end of the pipe nipple through the spacer and then into the hole of the bearing. The bearing should already be firmly attached to the wooden pedestal of the Barany Chair. Make sure the chair rotates freely above the pedestal. Reach through the access door of the pedestal and twist and tighten the remaining lock nut on to the lower end of the Barany Chair. The chair should now rotate freely with no wobble. Close the access door. If you have not already done so, attach the seat restraint to the back or the rear of the arms of the chair. The Classroom Barany Chair is now finished and ready to be used.

Notes About Selecting the Chair Seat:
Office supply and furniture stores offer a wide range of office chairs. It is recommended that a “task chair” with arms be selected for the Barany chair. Before obtaining the chair, check to make sure it does not have a seat tilt adjustment. While a chair with tilt adjustment will work, the method for mounting the pipe nipple and lock nuts shown above may have to be modified. Task chairs without tilt adjustments have simpler seat brackets and easier to mount as illustrated above. Be sure to use at least one lock nut immediately beneath the bracket (two are shown here).
(The following is a partial list of office chair brand names that offer task chairs without seat tilt mechanisms: Novimex, Numark, Global, OFM, and Hom.)

Maintenance Instructions:
If the chair seat begins to wobble as it rotates, tighten the lock nuts until the chair no longer wobbles.

Vestibular Illusions– Using the Barany Chair in the Classroom

The Classroom Barany Chair creates powerful vestibular illusions (spatial disorientation phenomena). As explained in the introductory sections of this publication, humans sense position and motion in three-dimensional space through the interaction of a variety of body proprioceptors, including muscles, tendons, joints, vision, touch, pressure, hearing, and the vestibular system. Feedback from these various systems is interpreted by the brain as position and motion data.

The Classroom Barany Chair enables you and your students to isolate the vestibular so that motion is interpreted solely on the basis of vestibular feedback. The test subject perceives motion when none is taking place, perceives motion in a different direction from that which is actually taking place, or fails to perceive motion at all.

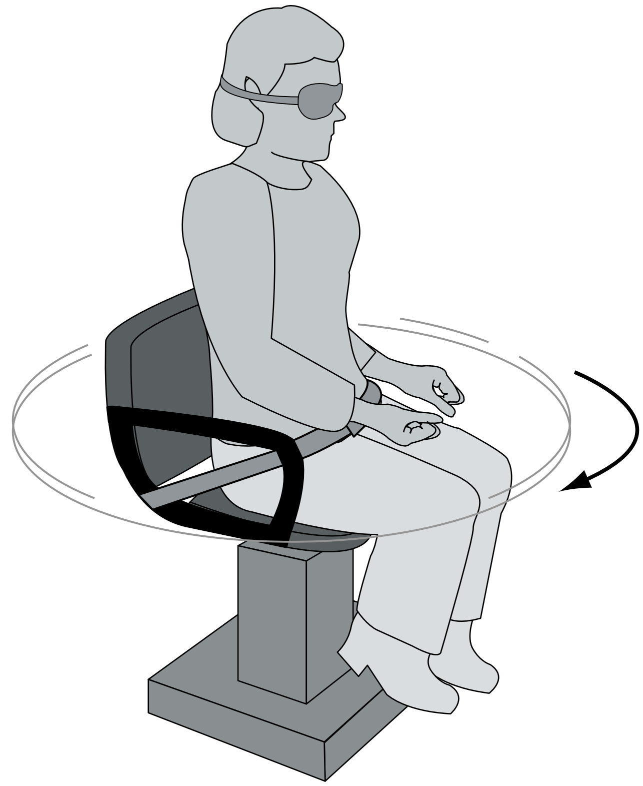
To experience these illusions, a volunteer is placed on the seat of the Barany Chair and strapped in with the lap restraint. A blindfold is placed over the volunteer's eyes and all observers remain silent. By removing vision and minimizing hearing, vestibular inputs dominate. How the chair is rotated and how the volunteer holds his or head determines which of five vestibular illusions described here is experienced.

Preparation

Clear an area of your classroom large enough to accommodate the chair in its center with observer students in a circle several feet back. Ideally, the room will not have windows or if it does, the windows will have with room-darkening shades. Place the chair in the middle of the room. Make sure the chair is level.

Selecting Test Subjects

The vestibular illusions created by the Barany Chair can produce nausea in some test subjects. Ask volunteers if they are able to ride spinning amusement park rides without becoming sick.



The Barany Chair rider indicates the direction the perceived direction by pointing his or her thumbs.

Even though the Barany Chair moves much more slowly than the rides, it can produce sickness. Most volunteers should be able to experience Illusions 1 and 2 with only momentary disorientation. Illusions 3 through 5 produce stronger effects. (Note: Do not attempt Illusion 5 with any volunteers. Illusion 5 is described here to help you understand the Coriolis illusion and the problem pilots and astronauts face when more then one semicircular canal is stimulated simultaneously. It is highly likely that the volunteer will become sick.)

Illusion 1 – Sensing Yaw Motion

What to Do

Place the volunteer on the chair with fists resting on his or her thighs and head upright. Instruct the volunteer to make the "thumbs-up" sign with each hand. Tell the volunteer to rotate the wrists so that the thumbs point in the direction of movement. If the movement changes to a different direction, the wrists should be rotated so that the thumbs point in that direction. If do not perceive any motion the thumbs should be pointed upwards. Finally, cover the volunteer's eyes with the blindfold. Touching only the seatback of the chair, give the chair a spin. Input enough force into the chair to rotate it eight to ten times on one push. If necessary, give the chair an additional gentle push to keep it rotating. Gripping the chair back, slow the chair to a rapid but smooth stop. Wait a few moments to observe thumb movements and then remove the blindfold. Tell the volunteer to stare at a fixed point on the wall.

What Happens

At first, the volunteer will point thumbs in the same direction the chair is rotating. After stopping the chair, the volunteer will reverse the direction of the thumbs, indicating counter rotation. Upon opening his or her eyes, the volunteer will experience rapid flicking motions of the eyes from side to side. The flicking eye movement can be observed staring directly at the volunteer's face.

Why

The rotation of the chair causes the fluid or endolymph within the yaw axis semicircular canal to begin moving. At first, the inertia of the fluid causes it to lag behind the motion of the subject's body. This causes the cupula (containing hair cells inside) to bend. Now stimulated, the hair cells send signals to the brain telling it that motion has been initiated in what speed and direction. When the chair is stopped, the momentum of the now moving endolymph causes it to continue moving even though the volunteer's head and semicircular canals have stopped. The hair cells are now bent in the exact opposite direction as before. This sends a false signal to the brain that the direction of motion has reversed. The flicking eye movement, called nystagmus, shows that the vestibular and vision systems are linked. The eyes try to help the volunteer see effectively for the illusory counter rotation. They flick in an attempt to track objects, which the brain mistakenly believes are coming into the field of view.

Movies Can Make You Sick

Giant screen film theaters in museums and science centers often feature productions containing wild treetop level flight scenes. The screen is so large that viewers often feel like they are part of the action even when they are sitting perfectly still. People will lean with the airplane as it maneuvers. Without arm rests, some people would actually lean far enough over to fall to the floor. The visual effect can be nauseating because the visual and vestibular systems are in conflict. However, nausea problems are easily corrected by simply closing the eyes. All sensations of motion then stop.

Vestibular Illusion 2 – Failure to Sense Motion

What to Do

Set up the illusion in the same way as you did for Illusion 1. Put a dark blindfold on the volunteer and provide ear protection to diminish the ability to hear. These additions are necessary because the failure to sense motion is a difficult illusion to achieve. The illusion is easily interfered with by unintended feedback from other proprioceptors. For example, a nearby student whispering will provide auditory cues to the chair rider that the chair is or is not rotating. If the room you are using the chair in has light and dark areas, the volunteer will see changes in brightness through the eyelids during rotation. A blindfold and ear covers will assist in isolating the vestibular system. Rotate the chair as before and have the volunteer identify the direction of motion with the thumbs. Keep the chair spinning 10 or 15 times before very gently stopping it. As with the first illusion, the volunteer should point his or her thumbs in the direction of perceived movement or upward if the volunteer perceives that motion has stopped.

What Happens

The volunteer will perceive the start of motion by pointing his or her thumbs in the direction of rotation. After a number of rotations, the volunteer will point the thumbs upward even though the chair is still rotating. Finally, the volunteer will point thumbs the opposite direction from the first movement to indicate counter rotation.

Why
As with the first illusion, endolymph in the yaw semicircular canal will lag behind the initial motion. Signals sent to the brain will be interpreted that the body is rotating in a particular direction. Gradually, the endolymph in the yaw semicircular canal will catch up with the motion and stimulation of the hair cells in this canal will stop. The brain will falsely interpret the lack of stimulation hair cell stimulation to mean that the chair has come to rest. Later, when the chair slows down the momentum of endolymph will cause it to continue to flow through the yaw canal. Stimulation in the opposite direction will be falsely interpreted as counter rotating.

Vestibular Illusion 3 – Sensing Roll Motion

What to Do
Have the volunteer grip the arm rests with both hands. After putting the blindfold in place, instruct the volunteer to drop his or her chin to the chest and close the eyes. Spin the chair at least 10 times. Bring it to a smooth stop. Tell the volunteer to sit up straight and open his or her eyes.

What Happens
The volunteer will experience a powerful cart wheeling sensation to the left or right (depending upon the spin direction) upon opening his or her eyes. It will be difficult for the volunteer to remain sitting straight up and instead will tend to lean aggressively to one side or the other.

Why
By tilting the head forward, the roll axis semicircular canal will be brought into the same plane of rotation as the Barany Chair. By stopping the chair and tilting the head back to the vertical position, the roll axis will be repositioned while the endolymph fluid is still moving in the roll axis canal. This will cause a strong sensation of cart wheeling movement. The volunteer will try to lean in the opposite direction to compensate for the effect. (Important Safety Note: Remain near the chair and be ready to offer physical assistance in case the rider loses grips on the arm rests and tries to roll off the side of the chair. Do not attempt this experiment without a "spotter.")

Vestibular Illusion 4 – Sensing Pitch Motion

What to Do
Have the volunteer grip the arm rests with both hands. Instruct the volunteer to lean forward slightly and turn the head as far to the side as possible. Spin the chair at least 8 times in the direction the volunteer is facing. Bring it to a smooth stop. Tell the volunteer to sit back and bring the head to the upright position and open his or her eyes.

What Happens
The volunteer will sense that he or she is tumbling backwards and will even have a difficult time sitting up.

Why
By leaning forward and tilting the head to the side, the pitch axis semicircular canal will be brought into the same plane of rotation as the motion of the Barany Chair. After stopping and returning to the upright position, endolymph fluid will continue to move in the pitch axis canal. This will cause a strong sensation of tumbling. The volunteer will readjust his or her body position in order to counteract the perceived movement. (Important Safety Note: Remain near the chair

and be ready to offer physical assistance in case the rider loses grips on the arm rests and tries to flip off the chair. Do not attempt this experiment without a "spotter.")

Vestibular Illusion 5 – Coriolis Illusion

(Important Safety Note: Do not attempt this illusion. The description that follows is for illustrative purposes only. The Coriolis Illusion is the most powerful of the illusions described in this publication and it can result in total disorientation, dizziness, and nausea.)

What to Do
Have the volunteer grip the arm rests with both hands. Instruct the volunteer to lean forward slightly and turn the head to the side. Spin the chair at least 6 times. While keeping the chair rotating and the volunteer's the eyes still closed, instruct the volunteer to sit upright again. Continue the spinning the chair two more times. Tell the volunteer to open his or her eyes. (Important Safety Note: Remain near the chair and be ready to offer physical assistance in case the rider loses grips on the arm rests and tries to tumble off the chair. This illusion may lead to nausea and it is prudent to have a wastebasket and towels available just in case.)

What Happens
The volunteer becomes totally disoriented and may become nauseous.

Why
In the Coriolis illusion, the endolymph in more than one canal is moving at the same time. In this example, it is the pitch and yaw canals that are stimulated. For airplane pilots, this illusion can be disastrous if it occurs near the ground. If visual conditions are good, the pilot can see that something is amiss but in limited visibility situations, the pilot may spiral the airplane into the ground. To attempt to prevent this situation, pilots are schooled to recognize the symptoms and to trust the airplane's instruments.

Special Note: While it is possible to stimulate all three semicircular canals with the Barany Chair, it is not recommended. Simultaneous stimulation of the three canals can occur in aerobatic flight and in space flight, leading to total spatial disorientation sensation.

Other Uses for the Classroom Barany Chair

The classroom Barany Chair is ideal for a variety of physics and technology demonstrations.

•Conserving Angular Momentum – Hand the volunteer small barbells to extend at arm's length during the initial rotation. By bringing the barbells in toward the chest, the rotation rate will increase. This demonstration gives the illusion of getting something for nothing. The rotation rate increases because the barbells are traveling in a smaller circle than before. To conserve their angular momentum, the rotation rate has to increase. Extending the barbells back outward slows the rotation rate but angular momentum is still conserved.

• Newton's Laws of Motion – Hand the volunteer an electric leaf blower. While helping the cord from wrapping too tightly around the pedestal, have the student turn on the blower and direct the exhaust at right angles. The chair will begin to accelerate in one or the other direction. After a few rotations, the exhaust should be redirected to the other direction, causing the chair to decelerate. The rotational movement of the chair demonstrates Newton's First and Third Laws. The rate at which the chair accelerates or decelerates demonstrates the Second Law.

• Working In Space – Firmly hold a threaded pipe joint over the head of the volunteer. Have the volunteer screw a pipe nipple tightly into the joint. This demonstration illustrates why spacewalking astronauts require foot restraints as they work outside of the International Space Station. Newton's Third Law of Motion comes into play. The chair simulates microgravity. Without a fixed anchor point, the astronaut rotates in the opposite direction from the turning motion.

Supplementary Teaching Aids

The following items will assist you in explaining how the vestibular system functions:

- Three-dimensional cutaway model of the human ear. (Available from school science catalogs.)
- Gelatin Ring Mold Canal Model (see below)
- Three Axis Canal Model (see right)

Three Axis Canal Model

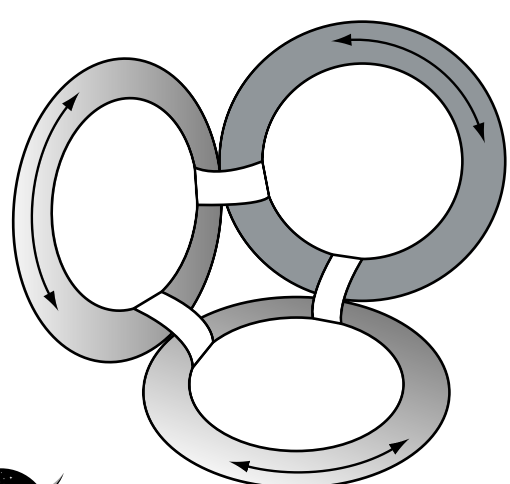
Materials:
Nine feet of 1” vinyl hose (hardware store)
3 plastic hose connectors (hardware store)
Plastic tape
Water and basin
Glitter

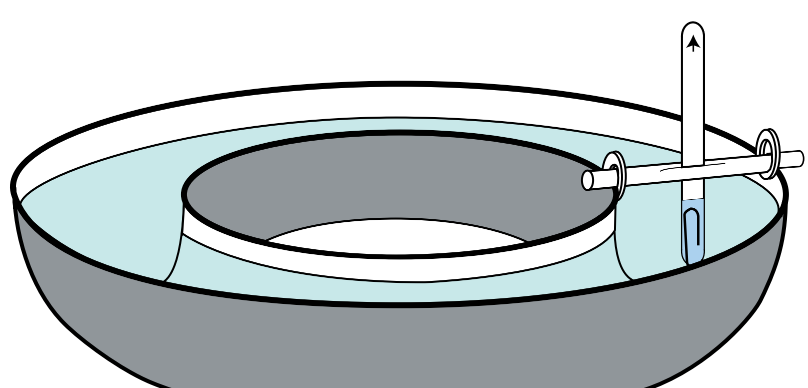
1. Cut the hose squarely in three equal pieces.
2. Fill a basin with water.
3. Put about a teaspoon of glitter in the first hose and immerse the hose in the water to remove any air from the hose.
4. Jam the hose on to the ends of a connector. Remove the hose and repeat with the other two hoses.
5. Join the hose rings together as shown above. Place the model on the seat of the Barany chair and rotate the chair. Only the fluid in the Yaw plane canal will move. The presence of the glitter will help you see the motion. Try different orientations of the model on the chair to see what effects it has on the different canals. Compare these orientations to the vestibular illusions.

Gelatin Ring Mold Canal Model

Materials:
Gelatin ring mold
2 metal washers
1 plastic soft drink straw
1 wooden craft stick
Hot glue and gun
Paper clip
Sharp knife
Water
Lazy Susan turntable

1. Glue the two washers on the rim of the mold as shown in the diagram below.
2. Cut a slit through the sides of the straw at the midpoint.
3. Sllide the straw through the two washers.
4. Slip the craft stick through the slits in the straw so that the lower end almost touches the bottom of the mold.
5. Attach a paperclip to the lower end of the craft stick for ballast.
6. Place the model on the turntable the mold and fill half way with water. Slowly rotate the mold. The inertia of the water will cause it to lag behind. This will tilt the stick so that it is pointing in the direction of motion. As friction with the mold walls causes the water to move, the stick will return to the upright position. When the mold is stopped, the momentum of the water will cause the stick to point in the opposite direction. This is a visual demonstration of what happens during Vestibular Illusion 2.





Place on turntable (lazy Susan)

Additional Resources

Websites

Space Research - NASA's Office of Biological & Physical Research
Latest Biological and Physical Research news, research on the International Space Station, articles on research activities, educational resources
http://SpaceResearch.nasa.gov

Space Biology - An Educator's Resource
Geared toward high school and undergraduate college students and instructors. Topics cover research, resources, and images
http://www.spacebio.net

Neuroscience Laboratory at the NASA Johnson Space center
Facility description and latest research programs
http://www.jsc.nasa.gov/sa/sd/facility/labs/Neuroscience/neuro.htm

NASA Spacelink

Official home to electronic versions of NASA"s Educational Products. Educators and students can search and download educator guides, educational briefs, lithographs, and other educational materials. Using Spacelink Search, educators and students can easily find information among NASA's thousands of Internet resources. Special events, missions, and intriguing NASA web sites are featured in Sapcelink's "Hot Topics" and "Cool Picks" areas.
http://spacelink.nasa.gov

NASA CORE
For information about multimedia products available for a minimal charge, visit the Central Operations of Resources for Educators (COERE) website at:
http://core.nasa.gov

NASA Education Home Page
NASA's Education Home Page serves as the education portal for information regarding educational programs and services offered by NASA for the American educational community. This high level directory of information provides specific details and points of contact for all of NASA's educational efforts, Field Center offices, and points of presence within each State.
http://eduction.nasa.gov

NASA Life Sciences Data Archive
Space flight experiment results and photo gallery
http://lsda.jsc.nasa.gov

National Space Biomedical Institute
Education materials
http://www.nsbri.org/Education/index.html

Canadian Space Agency - Resources for Educators
Activities and fact sheets
http://www.space.gc.ca/kidspace/1-edu_res/resources/all/default.asp

Barany Chair History
http://www.nobel.se/medicine/laureatea/1914/barany bio.html

Publications

(1998), *The Brain In Space, A Teacher's Guide With Activities for Neuroscience*, EG-1998-03-118-HQ, National Aeronautics and Space Administration, Life Sciences Division, Washington, DC.
This publication can be obtained at the folowing address: *http://spacelink.nasa.gov/Instructional.Materials/NASA.Educational.Products/The.Brain.in.Space/*

Rogers, M.J., Vogt, G.L., and Wargo, M.J., (1997), *Microgravity - A Teacher's Guide with Activities in Science, Mathematics, and Technology*, EG-1997-08-110-HQ, National Aeronautics and Space Administration, Washington, DC.
This publication can be obtained at the folowing address: *http://spacelink.nasa.gov/Instructional.Materials/NASA.Educational.Products/Microgravity/*

Long, Michael E. (2001), *Surviving in Space*, National Geographic, v 199, n1, pp 6-29.

Barany Chair History
http://www.nobel.se/medicine/laureatea/1914/barany-bio.html

Evaluation
Please take a moment to evaluate this product at

http//:ehb2.gsfc.nasa.gov/edcats/educational_brief

Your evaluation and suggestions are vital to continually improving NASA educational materials. Thank you.